VERIFICATION

I, Tetsuji Kodaira

of 3rd Floor No.8 Kikuboshi Tower Building, 20-18 Asakusabashi 3-chome, Taito-ku, Tokyo, JAPAN 111-0053

do hereby verify that I am fully conversant with the Japanese and English languages and that attached translation signed by me is, to the best of my knowledge and belief, a true and correct English translation of the Japanese Patent Application No. 9-280810.

DATED May 11, 2004

SIGNED T. Kodaira

PATENT OFFICE

JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this office.

Date of Application: October 14, 1997

Application Number: H09-280810

Applicant(s): NGK Insulators, Ltd.

Commissioner,

Patent Office

[NAME OF DOCUMENT] APPLICATION FOR PATENT

[SERIAL NUMBER] WP02401

[FILING DATE] October 14, 1997

[ADDRESSEE] Hisamitsu Arai
Commissioner of the Patent Office

[INTERNATIONAL PATENT CLASSIFICATION] H01M 10/36
H01M 10/38

[TITLE OF THE INVENTION] LITHIUM SECONDARY BATTERY

[NUMBER OF CLAIMS] 6

[INVENTOR]

[Address or Residence] c/o NGK Insulators, Ltd. 2-56, Suda-cho, Mizuho-ku, Nagoya-city, Aichi-prefecture

[Name] Kenshin Kitoh

[INVENTOR]

[Address or Residence] c/o NGK Insulators, Ltd. 2-56, Suda-cho, Mizuho-ku, Nagoya-city, Aichi-prefecture

[Name] Hiroshi Nemoto

[APPLICANT FOR PATENT]

[Identification number] 000004064

[Name] NGK Insulators, Ltd.

[AGENT]

[Identification number] 100088616

[Patent Attorney]

[Name] Kazuhira Watanabe

[OFFICIAL FEE]

[Payment registered number] 009689

[Amount of payment] ¥21,000

[LIST OF SUBMITTED DOCUMENTS]

[Name of document]	Specification: 1
[Name of document]	Drawings: 1
[Name of document]	Abstract: 1
[General power of attorney number]	9001231

[PROOF] Necessary

[Name of Document] SPECIFICATION

[Title of the Invention] LITHIUM SECONDARY BATTERY

[Scope of the Claim for Patent]

[Claim 1] A lithium secondary battery, wherein an internal electrode body is housed in a battery case; said internal electrode body being formed by winding or laminating a positive electrode and a negative electrode through a separator made of porous polymer so that the positive electrode and the negative electrode are not brought into direct contact with each other,

characterized in that said battery case is composed of pure aluminum or an aluminum alloy in which one or more components selected from manganese, magnesium, silicon and copper is added in aluminum.

[Claim 2] A lithium secondary battery according to claim 1, characterized in that a relationship of $C/(w \cdot c) \leqq 0.03$ is established, where current capacity is C (Ah), battery weight is w (kg), and specific heat of the battery is c (W/kg·℃).

[Claim 3] A lithium secondary battery according to claim 1 or 2, characterized in that a relationship of $0.004 \leqq t/d \leqq 0.04$ is established where said battery case is cylindrical, its outer diameter is d (mmφ), and its wall thickness is t (mm).

[Claim 4] A lithium secondary battery according to any one of claims 1 to 3, characterized in that current capacity is 50 Wh or more.

[Claim 5] A lithium secondary battery according to any one of claims 1 to 4, characterized in that it is used for an electric vehicle or a hybrid electric vehicle.

[Claim 6] A lithium secondary battery according to any one of claims 1 to 5, characterized in that lithium-manganese oxide ($LiMn_2O_4$) is used as a positive active material.

[Detail description of the invention]

[0001]

[Technical field of the invention] The present invention relates to a lithium secondary battery which is superior in safety, and has high weight energy density [energy stored per unit weight, (hereinafter referred to as "energy density")], particularly used suitably for an electric vehicle.

[0002]

[Prior art] In recent years, a lithium secondary battery is becoming rapidly popular as a small power source for a portable electronic equipment. In addition, development of a lithium secondary battery is in progress for motor driving of an electric vehicle which replaces a gasoline-powered vehicle, or a large capacity and large size battery as a battery for storing electric power at night to realize practical use early.

[0003] The structure of a lithium secondary battery is roughly divided into a wound type shown in Fig. 2 and a laminated type shown in Fig. 3. An internal electrode body 1 of the wound type is constituted by winding a positive electrode 2 and a negative electrode 3 through a separator 4, whereby the positive electrode 2 or the like having a large area can be housed in a tubular container. In the case of this wound type, it has such advantages that the internal does not become complicated structure and that the assembly of the battery becomes simple, since it is sufficient that there is at least one lead 5 from each electrode 2, 3, and, even if it is desired to lower current collection resistance

of each electrode 2, 3, it is sufficient to increase the number of leads.

[0004] On the other hand, an internal electrode body 7 of the laminated type is constructed by alternately laminating positive electrodes 8 and negative electrodes 9 in multiple layers through separators 10, in which area per one positive electrode 8 or the like is not so large, but the electrode area of the entire battery can be increased by laminating them in multiple layers. The internal electrode body 7 being produced can be designed into any desired shape such as a type of a rectangular parallelepiped, a disc or a tube, depending on the shape of each of electrodes 8, 9 and the number of laminations. However, since a lead 6 is necessary for each electrode 8, 9, there is such a disadvantage that the internal structure of a battery becomes complicated, and that it is inferior to the wound type in view of assembly workability of a battery.

[0005] In both the wound type and laminated type structures, the internal electrode body is placed in a metal battery case so that each of the electrodes and the leads do not contact each other. Conventionally, stainless steel is most widely used for this battery case, and sometimes nickel, titanium or the like may be used.

[0006]

[The problems to be solved by the invention] However, since stainless steel or nickel has higher specific gravity, there is a disadvantage that, when it is used for the battery case, the battery itself becomes heavy, so that the energy density becomes low. On the other hand, while titanium has an advantage to have lower specific gravity than stainless steel or nickel, and to be excellent in corrosion resistance, it is

expensive, and its use is limited to a specific application such as space development, so that it is difficult to use as a general purpose battery component. In addition, in the lithium secondary battery, it is often the case that the battery case itself is used as a current path for the positive side or negative side, and such material has high electric resistance, leading to a cause of power loss. In addition, such material is not always said to have good workability as the battery case.

[0007] Under such circumstances, as a lithium secondary battery for an electric vehicle (EV) or hybrid electric vehicle (HEV), it is required to have a cell capacity of at least 50 Wh, to have light weight so as not to increase weight of the vehicle itself, and to have high safety. To meet such requirements, stainless steel with high melting point and high strength has been conventionally used by particularly taking safety into consideration. However, as described earlier, it is difficult to solve the problem for reducing weight of the battery. In addition, EV and HEV require a high current in acceleration, therefore, magnitude of electric resistance of the battery case cannot be ignored, when the battery case is used as the current path, and there remains a problem on workability of a large sized battery case. When nickel or titanium is used, such problems are also difficult to be solved because of physical characteristics of these materials.

[0008] Then, to solve such problems, the inventors have studied the capability of aluminum to be used as the battery case, which has lightweight, is excellent in electron conductivity, and is of good workability. There is no precedent to use aluminum as a battery case for a large

battery of 50 Wh or more. That may be because the melting point of aluminum is as relatively low as 660℃,that is significantly lower than those of the above materials, and, it would be concerned that the potential of exhalation, combustion, or in the worst case, explosion of an electrolyte, when the battery case is softened or melted due to erroneous use or the like.

[0009] Also, in "Guideline for Safety Evaluation on Secondary Lithium Cells" (commonly called "SBA Guideline") established by Battery Association of Japan, it is stipulated that the battery does not burst or fire, even if fully charged entire energy is instantaneously discharged by external short-circuit or internal short-circuit caused by a nail piercing test or the like, and then the lithium secondary battery generates heat.

[0010] While it is strictly required to assure such safety, the inventors found that, even when an aluminum battery case is used, the problems on safety could be solved by accurately measuring temperature rise on the surface of the battery to calculate specific heat of the battery, and identifying the relationship between the battery capacity and the weight, further, reduction of energy density could be prevented by optimizing the shape of the battery case, and thus reached the present invention.

[0011]

[Means to solve the problem] That is, according to the present invention, there is provided a lithium secondary battery, wherein an internal electrode body is housed in a battery case; said internal electrode body being formed by winding or laminating a positive electrode and a negative electrode through a separator made of porous polymer so that

the positive electrode and the negative electrode are not brought into direct contact with each other, characterized in that said battery case is composed of pure aluminum or an aluminum alloy in which one or more components selected from manganese, magnesium, silicon and copper is added in aluminum.

[0012] In addition, in the lithium secondary battery of the present invention, it is preferable, in view of assuring safety of the battery, that a relationship of $C/(w \cdot c) \leqq 0.03$ is established, where current capacity is C (Ah), battery weight is w (kg), and specific heat of the battery is c (W/kg·℃). It is also preferable, in view of attaining both high energy density and safety, that a relationship of $0.004 \leqq t/d \leqq 0.04$ is established, where the battery case is cylindrical, its outer diameter is d (mmϕ), and its wall thickness is t (mm). Moreover, such conditions are preferably applied to a lithium secondary battery with battery capacity of 50 Wh or more. The lithium secondary battery satisfying such conditions is preferably used for an electric vehicle or a hybrid electric vehicle. In addition, lithium-manganese oxide ($LiMn_2O_4$) is preferably used as a positive active material in the lithium secondary battery of the present invention.

[0013]

[Mode for carrying out the invention] As described above, the lithium secondary battery of the present invention aims to reduce weight of the battery case while assuring high safety, in consequence, to have a high energy density.

Hereinafter, embodiments of the present invention will be described, but the present invention is not limited to these embodiments.

[0014] An internal electrode body in the lithium secondary battery of the present invention is composed of winding or laminating positive and negative electrodes through separator film of porous polymer such that the positive electrode and the negative electrode do not directly contact each other. Specifically, it includes the structures shown in Figs. 2 and 3, that is, internal electrode bodies 1 and 7.

[0015] As a positive electrode plate, it can be used that a material that is an aluminum foil applied with a mixture of a positive active material and carbon powder to improve conductivity. As the positive active material, for example, lithium-cobalt oxide ($LiCoO_2$), lithium-nickel oxide ($LiNiO_2$), or lithium-manganese oxide ($LiMn_2O_4$) can be exemplified, and in the present invention, $LiMn_2O_4$ is preferably used. In addition, as carbon powder, for example, acetylene black, a graphite powder or the like can be cited. In addition, as the aluminum foil constituting the positive electrode plate, it is preferable to use a material with high purity to prevent a battery performance from lowering due to corrosion by an electrochemical reaction of the battery.

[0016] On the other hand, as the negative electrode plate, it is preferable to use a material that is a copper foil coated with an amorphous carbon material such as soft carbon or hard carbon, or carbon powder such as natural graphite. Here, for the copper foil used as the negative electrode, it is preferable to use a material with high purity to withstand the corrosion due to an electrochemical reaction as well as the aluminum foil used for the positive electrode plate.

[0017] In addition, when the above-mentioned carbon material is used for the negative electrode, it is known that a part of lithium ions adsorbed to the carbon material at the initial charging reaction of the battery becomes so-called dead lithium, which is kept adsorbed to the carbon material, and becomes the condition that does not contribute to the subsequent charging and discharging reactions, so that it causes lowering of the capacity of the battery. Thus, it is preferable to select a material in which the amount of the dead lithium is small as the carbon material for the negative active material.

[0018] As a material of the separator film, it is preferable to use that a three-layer structural material in which a polyethylene film having lithium ion permeability and including micropores is sandwiched between porous polypropylene films having lithium ion permeability. This serves also as a safety mechanism in which when the temperature of the internal electrode body rises, the polyethylene film is softened at about 130℃ so that the micropores collapse to suppress the movement of lithium ions, that is, the battery reaction. And by means of putting the polyethylene film between the polypropylene films having a softening temperature higher than that of the polyethylene film, it is possible to prevent the contact and the adhesion between the separator film and positive and negative electrode.

[0019] The internal electrode body produced using such material is housed in the battery case. In the present invention, it is used that a battery case composed of pure aluminum or aluminum alloy in which one or more components selected at least from manganese, magnesium, silicon and

copper is added in aluminum. Here, pure aluminum does not refer to aluminum with 100% purity, but may contain impurities, which are unavoidably mixed during an ordinary refining or manufacturing process, and, more specifically, it is preferable when the purity comes to 99% or more. In addition, as for the aluminum alloy, also it does not mean that impurities unavoidably mixed during an ordinary manufacturing process are excluded from aluminum that is the main component. As specific examples of aluminum alloy, alloy No. 3203 (aluminum-manganese alloy) prescribed in JIS and the like can be mentioned.

[0020] Here, the aluminum battery case means that a main portion of the battery case, that is, a container is made of aluminum, where the internal wound body is inserted to place in the container, and a sealing member for sealing an opening of the battery case is not necessarily made of aluminum. For example, when the internal electrode body is a cylindrical wound body shown in Fig. 2, it is sufficient that at least a cylindrical container opened at both ends, or a bottomed cylindrical container opened at only one end is made of aluminum, alternatively, when the internal electrode body is a rectangular parallelepiped laminated body shown in Fig. 3, it fulfills the condition of the battery case that may be preferably used for the present invention, as long as at least a tubular container with an approximately rectangular section or a rectangular parallelepiped box-like container opened only at one side is made of aluminum.

[0021] The reason why the opening or the like for inserting internal electrode body is excluded from the battery case lies in that there are the cases that it is preferable to constitute the sealing member for sealing the opening of the

battery case from an insulating material such as heat resistant resin or ceramics, for the purpose of installing an external terminal for taking out electric energy from the internal electrode body or isolating an electric path each of the positive and negative electrodes within the battery. Of course, the above example of the battery case does not exclude a battery case which can be entirely composed of aluminum in the aspect of the battery by disposing insulating materials at appropriate locations to retain electric paths for the positive and negative electrodes, and using an aluminum part for the sealing member.

[0022] Then, the battery is produced by the internal electrode body, the battery case and other necessary members such as electrode terminals. In this case, as for the structure for the battery being produced, it may be possible to adopt a structure that enlarges a structure of a known small battery keeping the structure. In addition, the inventors have proposed a structure of lithium secondary battery in which various pressure-releasing mechanisms are disposed at appropriate locations in J-P-A-09-202963, and such structure may be also preferably employed. Moreover, it is preferable to install at least one pressure release valve on the produced battery case, which releases the internal pressure of the battery to the ambient air pressure when the internal pressure of the battery rises and reaches a predetermined pressure due to erroneous use of the battery or the like, thereby, an explosion due to a rise in internal pressure of the battery is avoided.

[0023] In the present invention, it is preferable to design the battery so as to establish the relationship of $C/(w \cdot c) \leqq 0.03$, where current capacity of the battery produced as just

described by using the aluminum battery case is C (Ah), the battery weight is w (kg), and the specific heat of the battery is c (W/kg·℃). Herein, the specific heat c of a battery is defined to be output (W) necessary for raising temperature of 1 kg of a battery by 1℃. Therefore, even if the same battery case is used in producing battery, the battery would have different specific heat if a component other than the battery case differs, while, even if the volume of a battery is the same, the battery would have different specific heat depending on the material and wall thickness of the battery case, the size of the internal electrode body or the like.

[0024] However, when the construction conditions are established to assure safety even if all energy which the battery can store is used to raise temperature of the battery, that is, the battery is arranged such that the relationship of $C/(w \cdot c) \leqq 0.03$ is established, it is possible to obtain a battery, in which temperature rise by generated heat does not cause softening or melting of the battery case, and which can clear the safety criteria of the SBA Guideline, even if fully charged entire energy is Instantaneously discharged by external short-circuit or internal short-circuit caused by a nail piercing test.

[0025] In addition, it is preferable in the present invention that the relationship of $0.004 \leqq t/d \leqq 0.04$ is established where the battery case is cylindrical, the outer diameter of the battery case is d (mmϕ), and the wall thickness is t (mm). For example, in the case where a wall thickness t of a battery case is thin, when a outer diameter d of the battery case is constant, that is, the value of t/d

is small, the energy density of the battery increases since the weight of the battery case decreases as the battery capacity increases, and a problem in safety arises since the strength of battery case is lowered. On the other hand, in the case where the wall thickness t of the battery case is thick, that is, the value of t/d is large, it is desirable from the viewpoint of safety since the strength of the battery case is heightened, but a problem arises, that the energy density is reduced as a whole since the weight of the battery case increases, and the battery capacity also decreases.

[0026] Thus, when the battery is arranged to have a ratio of the outer dimension of a battery case to the wall thickness in a specific range, it becomes possible to assure safety while maintaining the energy density of the battery at a proper high value.

[0027] In addition, in the case where the battery case is a rectangular parallelepiped, the above relational expression can be analogously applied by assuming that an outer diameter of a circle, which has the same area as the cross sectional area perpendicular to the longitudinal direction, is the outer diameter d of the above-mentioned battery case.

[0028] As described above, the present invention is accomplished as the result of the study mainly on the possibility of use of an aluminum battery case for a battery having large capacity of which there has not been actual example of production, and the technical feature of the present invention is suitably adopted for a lithium secondary battery with battery capacity of 50 Wh or more. However, it is needless to say that there is no problem to adopt the structure of the battery with large capacity, for which the

safety criteria are strict mentioned above, for use in a battery with smaller capacity.

[0029] Thus, as for the battery with large capacity per unit cell produced by using a battery case composed of aluminum, there has excellent advantages that weight saving of the battery is achieved, and energy density becomes larger. Also, compared with a case where a plurality of batteries with small capacity are connected to obtain a battery with equivalent capacity, because of the number of series/parallel connecting points of the battery is reduced, contact resistance due to a connection of batteries can be reduced, also it becomes possible to aim for saving mounting space of the battery. Therefore, the lithium secondary battery of the present invention is suitable in applications such as the power supply for an electric or a hybrid electric vehicle or as various mobile power supplies.

[0030]

[Example] Hereinafter, examples of the lithium secondary battery according to the present invention are described, but it is needless to say that the present invention is not limited to these examples.

First, description is given of members and a battery structure commonly used for the examples. A positive electrode plate was formed of an aluminum foil coated with a mixture, in which carbon powder (acetylene black) for improving conductivity was added to lithium-manganese oxide ($LiMn_2O_4$) as a positive active material and mixed together. Also a negative electrode plate was formed of a copper foil coated with graphite powder. As a separator for separating the positive electrode plate from the negative electrode plate, a microporous separator made of polypropylene was

used. As an electrolyte, an electrolysis solution, prepared by dissolving a $LiPF_6$ electrolyte into a mixed liquid of ethylene carbonate (EC) and diethyl carbonate (DEC), was used. The battery was made to a cylindrical type which was formed by inserting a cylindrical internal electrode body, in which the positive and the negative electrode plates were wound through the separator, into a cylindrical battery case, then both ends of the case were sealed with the structure shown in Fig. 1.

[0031] Here, in Fig. 1, a lead 32 for collecting electricity, which is connected to either one of the positive or the negative electrode plate (not shown), was connected to a metal rivet 33 mounted on a disk 34 for sealing a battery case 39. Then, the disk 34 was provided with a pressure release valve 35 which would be burst when the internal pressure of the battery would reach a predetermined pressure, and caulked to the battery case 39 through ethylene propylene rubber 38 so that an external terminal 37 was electrically connected to the disk 34 through a metal ring 36, and that the disk 34, the metal ring 36 and the external terminal 37 were electrically insulated from the battery case. Thus, it was formed that a battery of cylindrical type with both ends being terminals, in which the external terminal for either one of the positive or the negative electrode was disposed on one end of the battery case 39.

[0032]

[Test for selecting battery case material] Then, batteries, of which the battery size of outer diameter is 50 mm ϕ and length is 245 mm, and having the above-mentioned structure were formed by using battery cases with 50 mm of outer diameter and 1 mm of wall thickness composed of various

materials listed in Table 1, and energy density of each battery was measured. Here, aluminum alloy was aluminum added with manganese, while SUS-304 was used as stainless steel. In addition, the disk 34 for sealing the end of battery case 39 was made of the same material as the battery case 39, and the electrode plate of which area was made equal was used so that capacity of all batteries became 100 Wh.

[0033]

[Table 1]

	Battery case material	Energy density(Wh/kg)
Example 1	Aluminum	116
Example 2	Aluminum alloy	115
Comparative example 1	Stainless steel	94
Comparative example 2	Nickel	89
Comparative example 3	Titanium	107

[0034] The energy density of each produced battery is included in Table 1. It is remarkably indicated that the battery case material with higher density tends to provide lower resultant energy density. That is, in the case of Comparative example 2 where nickel was used wherein density of the battery case material is the highest, the energy density was the lowest of 89 Wh/kg, and the energy density became higher as the density of battery case material decreased in the order of stainless steel (Comparative example 1), titanium (Comparative example 3), and aluminum (Examples 1 and 2). Examples 1 and 2 using aluminum according to the present invention provided energy density of

about 115 Wh/kg. Since the energy density was 94 Wh/kg for Comparative example 1 using stainless steel which had been generally used as a battery case material, the characteristic of energy density was improved by about 20% by using aluminum or aluminum alloy for the battery case. Examples 1 and 2 were believed to have similar energy density because there was no significant difference in density between aluminum and aluminum alloy. In addition, in this test, since the battery case was not used as a current path, and distance was very short between the lead connected to the disk for sealing the battery case and the external terminal, impact on the energy density due to difference of conductivity of the battery case materials (disk for sealing the battery case) used can be ignored.

[0035]

[Test for identifying battery case shape] Effectiveness in using aluminum for the battery case was demonstrated from the result of the test for selecting the battery case material described above. Then, batteries were produced with various wall thickness t by using aluminum for the battery case, fixing the outer diameter d of the battery case to 50 mm, and length of the battery to 245 mm, and varying the wall thickness t (mm) in view of improvement of energy density and securing of safety, and measured for energy density and bulging (deformation) of the battery case after completing 100 charging/discharging cycles with discharging rate of 0.2C and depth of discharge (D.O.D.) 100%. Table 2 lists the values of t/d and the results of the produced battery cases.

[0036]

[Table 2]

	t/d	Energy density (Wh/kg)	Bulging after 100 cycle(mm)
Comparative example 4	0.002	141	>0.5
Example 3	0.004	137	0.2
Example 4	0.01	130	0.1
Example 5	0.02	117	<0.1
Example 6	0.04	101	0.0
Comparative example 5	0.06	82	0.0
Comparative example 6	0.1	57	0.0

[0037] Although the outer diameter of the battery case is fixed, since the inner diameter of the battery case is reduced as the wall thickness of the battery case is thickened, the size of the internal electrode body which can be housed in the battery case is reduced; that is, the area of the electrodes is made small, so that the absolute value of battery capacity is decreased. In addition, as the wall thickness of the battery case is thickened, ratio of the battery case to the weight of the entire battery is increased. This increases the value of t/d as listed in Table 2. That is, as the wall thickness of the battery case is thickened, the energy density significantly tends to decrease.

[0038] Here, since Comparative example 4 has as small t/d as 0.002, it had a light battery case, and very high energy density of about 140 Wh/kg. However, it has large bulging of outer diameter of the battery case after the charging/discharging test of 100 cycles, and is found to have a problem in safety. On the other hand, Comparative example

5 had as large t/d as 0.06, so that no deformation of the battery case was observed after the charging/discharging test of 100 cycles, but it could not provide desired energy density of 100 Wh/kg or more due to increase of weight of the battery case and decrease of volume of the internal electrode body which could be housed in the battery case.

[0039] It is revealed from Table 2 that $0.004 \leqq t/d \leqq 0.04$ is preferable as the condition for assuring safety as well as output density of 100 Wh/kg, as shown in Examples 3 through 6. In addition, the most preferable characteristic can be attained with bulging suppressed to as low as 0.1 mm or less while maintaining high energy density by making $0.01 \leqq t/d \leqq 0.02$.

[0040]

[Test for measuring specific heat of battery] Then, specific heat was measured on Example 5, which had the value of t/d of 0.02 or the wall thickness of 1 mm, which was believed to be preferable from the viewpoint of the energy density and safety in the above-mentioned test for identifying shape of the battery case. The specific heat was measured by attaching a T-type thermocouple at a longitudinal center of the side of the battery, discharging the battery to 2.5 V at a current of 27 A in a 25℃ constant temperature bath, after constant current charging at 10 A and constant voltage charging at 4.1 V (6 hours in total), and measuring temperature rise of the battery. As a result, temperature rise was 6℃. Assuming that all heat generation from the battery when it is discharged is caused by internal resistance of the battery, since the internal resistance of battery was 4 mΩ, total power consumption in discharge

(resistance ×(current)^2 ×discharging time) was 8923 W. Therefore, for battery weight of 0.86 kg and temperature rise of 6℃, the specific heat of the battery was calculated as 1729 W/kg·℃.

[0041] When all energy (100 Wh) of this battery was assumed to be instantaneously discharged from the full charged state due to external short-circuiting caused by erroneous use or internal short-circuiting, since 100 Wh corresponded to 360000 W (100×3600 seconds), when this value is divided by the weight and the specific heat of the battery, the temperature rise of the battery was calculated as 242℃, and it was found that the highest temperature reached was lower than the melting point of 660℃ of aluminum. Then, when the external short-circuiting test was conducted in a state where the battery was actually fully charged, the pressure release valve was actuated but no burst or firing was occurred, so that safety of the battery was confirmed to be assured.

[0042]

[Internal and external short-circuiting tests] Batteries having various C/(w·c) values as shown in Table 3 were produced using an aluminum battery case by noticing the parameter of C/(w·c) consisting of the battery capacity C (Ah), the battery weight w (kg), and the specific heat c of the battery (W/kg·℃) calculated with the above method based on the result of the test for measuring specific heat of the battery mentioned above, and subjected to the nail piercing test(internal short-circuiting test) according to the SBA Guideline. Table 3 also lists the test results.

[0043]

[Table 3]

	C/(w·c)	Situation after test	Evaluation
Example 7	0.015	Pressure release valve worked; no burst nor firing	○ good
Example 8	0.018	Pressure release valve worked; no burst nor firing	○ good
Example 9	0.03	Pressure release valve worked; no burst nor firing	○ good
Comparative example 7	0.035	Pressure release valve worked; burst nor firing	× no good

[0044] As listed in Table 3, in the case of Examples 7-9 with C/(w·c) value of 0.03 or less, although the pressure release valve was worked, no significant change of shape was observed due to softening or melting of the battery case. However, in the case of Comparative example 7 with C/(w·c) value of 0.035, the battery case was significantly deformed and partially cracked, and traces which were believed to indicate partial melting were observed. In addition, as for Examples 7-9 and Comparative example 7, when similar batteries were again produced, and subjected to the external short-circuiting test by short-circuiting the external terminal, there were provided the same results as the internal short-circuiting test shown in Table 3. From this, it was confirmed that the safety criteria prescribed in the SBA Guideline could be passed by making the C/(w·c) value 0.03 or less.

[0045]

[Effect of the Invention] As described, according to the lithium secondary battery of the present invention, since aluminum, which has lightweight and is excellent in

conductivity, is used for a battery case, it has a very excellent advantage that the battery has light weight, and is significantly improved for the energy density than the prior art. Moreover, it is possible to provide a battery with excellent safety which can pass the criteria of SBA Guideline because the specific heat design of battery for the battery capacity and determination of shape of battery case are properly conducted.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a sectional view showing a structure at the end of a lithium secondary battery produced according to an embodiment.

[Fig. 2]

Fig. 2 is a perspective view showing a structure of a wound-type internal electrode body.

[Fig. 3]

Fig. 3 is a perspective view showing a structure of a laminated-type internal electrode body.

[Reference Numerals]

1…internal electrode body, 2…positive electrode, 3…negative electrode, 4…separator, 5…lead, 6…lead, 7…internal electrode body, 8…positive electrode, 9…negative electrode, 10…separator, 32…lead, 33…rivet, 34…disk, 35…release valve, 36…metal ring, 37…external terminal, 38…ethylene propylene rubber, 39…battery case